NATIONAL BUREAU OF STANDARDS REPORT

8359

EVALUATION OF RESISTANCE STRAIN GAGES
AT ELEVATED TEMPERATURES

Progress Report No. 16

by

J. T. Trumbo and R. L. Bloss

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Engineering Mechanics Section
Division of Mechanics

Technical Report

to

Bureau of Naval Weapons
Aeronautical Systems Division

Order No. IPR-19-64-8022-WEPS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

FOREWORD

In recent years the use of structures at elevated temperatures has increased greatly. If the safe design and efficient use of structural materials are to be assured, a knowledge of the mechanical properties of materials and of structural configurations is essential. In determining these properties, the measurement of strains and deformations is important. Strain gages to measure these quantities must be capable of operating satisfactorily over a wide temperature range.

In order to determine the characteristics of strain gages that are available for use at elevated temperatures, the Department of the Navy and the Department of the Air Force have sponsored a program for the evaluation of these gages. Results obtained from only one gage type are given in this report so that performance information may be made available without undue delay. Results obtained from other gage types have been presented in earlier reports of this series.

There is a continuing effort on the part of manufacturers and research organizations to develop improved strain gages for use at elevated temperatures. Therefore the results given in this report would not necessarily show the performance of similar gages which may differ in characteristics due to differences in materials, treatments, or methods of fabrication.

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Synopsis

Type FNW-FB-9-50-12 resistance strain gages, manufactured by the Baldwin-Lima-Hamilton Corporation, were evaluated. The results of these tests indicate that the gage factor for compressive loading is somewhat higher than for tensile loading; that the gage factor decreases with increasing temperature by about one-half percent per 100° F; that large errors can be expected when strains greater than 0.002 are measured; that the gages are well compensated for resistance instability; that the temperature sensitivity is low and repeatable from gage to gage, but the gage response is strongly affected by heating rate; and that the leakage resistance is influenced by temperature and the thermal history of the gage.

1. INTRODUCTION

In the continuing evaluation of resistance strain gages designed for use at elevated temperatures, type FNW-FB-9-50-12 gages of the Baldwin-Lima-Hamilton Corporation were tested to determine the following characteristics:

(1) Gage factor at room temperature,

(2) Variation of gage factor with temperature,

(3) Behavior when subjected to large strains,

(4) Change in indicated strain with time at constant temperature (drift),

(5) Change in indicated strain due to temperature changes,

(6) Behavior under transient heating conditions, and

(7) Resistance between the gage and the material to which it is attached.

The results of previous evaluations of other types of gages are given in references 1 through 13.

2. DESCRIPTION OF GAGES

Each of the gages consisted of four resistive elements as shown in figure 1. These elements are bonded to a piece of 0.005 inch thick shim stock by the manufacturer. For use, a gage is attached to a metallic surface by two rows of spotwelds along the center line of the shim material, and the gage leads are connected to form a full-bridge circuit (figure 1). A low temperature sensitivity over a large temperature range is sought by the proper choice of shim material and appropriate manufacturing techniques. According to the manufacturer, the gages tested were prestabilized, post cured and ready for use in the temperature range of -400° to 1000° F. The gages were ordered for use on material having a linear temperature coefficient of expansion of 9×10^{-6} per degree F.

3. TEST EQUIPMENT AND METHODS

The equipment and methods used for all these evaluation tests have been described in references 5, 8, 14, 15, and 16.

4. RESULTS AND DISCUSSION

The number of gages subjected to the various tests and the voltages applied to the gage circuits are shown in table 1. The heating rates used for the transient heating test are given in table 2. The results of the evaluation tests are given in table 3 and figures 2 through 24.

In order that the results of the tests might be readily compared with previous reports of this series, the gage response is given in terms of the relative change of resistance of one arm of a bridge circuit that would produce the same electrical output that was obtained from the full bridge circuit of the gage.

4.1 Strain Sensitivity

Gage factor values were obtained at about 75° F from four gages at a maximum strain of about 0.001 in both tension and compression. The gage response was determined by comparing the electrical output with the output of another bridge circuit of which two arms were a Wenner ratio set. Power to the bridge circuits was from separate power supplies, but the input voltages were compared and adjusted to be equal just prior to each reading. Readings were taken at predetermined settings of the Wenner ratio set by straining the specimen to which the gage was attached until the outputs of the bridge circuits were equal. The actual strain to which the gage was subjected was determined with a Tuckerman extensometer.

The results of these tests are given in table 3 where

K_u = the gage factor for increasing load,

K_d = the gage factor for decreasing load,

$\bar{K}$ = the average gage factor.

Gages A_1 and A_3 were tested in tension before being tested in compression. Gages A_2 and A_4 were tested in compression first.

The differences between the experimental gage factor values and the manufacturer's nominal value, 3.14, are shown in figure 2. The departure of a plotted point from the origin shows the difference between the experimental value and the nominal value. The departure of the points from the diagonal line show the differences between gage factor values for tension and compression loading. Results show that the gage factor values for compression loading were higher than for tension loading and that the value for the first loading cycle differed from values for subsequent tests.

Figures 3 through 6 show the departure from linearity of the gage response and the zero shift for the first and third loading cycles. The maximum strain was about 0.001. The gage factor, K, used in the data reduction was the manufacturer's nominal value, 3.14. The arrows on the curves indicate the direction of loading. No corrections were applied for temperature fluctuations during the tests.

4.2 Variation of Gage Factor with Temperature

The variations of gage factor with increasing temperature, obtained by dynamic test methods, are shown in figures 7 through 9. Each curve represents the change of gage factor of one gage during one test. Each figure gives the results obtained from one gage to show the repeatability of the gages from test to test.

Figure 10 shows the average variation of gage factor of three gages for each of the test runs and the extreme values obtained for any gage during any test. This shows that the gage factor tended to decrease in a linear fashion to 1000° F. The gage factors at 1000° F were about five percent less than at room temperature.

4.3 Large Strains

The results of tests in which the gages were subjected to tensile strains greater than those used for gage factor determinations are shown in figures 11 and 12. In order to compute the strains indicated by the resistance gage, $\epsilon_{Ind} = \frac{1}{K} \frac{\Delta R}{R}$, at room temperature the gage factor value, K, used was the average of all values obtained from the room temperature gage factor tests in tension. For the large strain test at 900° F, the room temperature value was adjusted by the average amount of change found during the first test runs of the variation of gage factor with temperature tests.

The errors of these gages tended to increase rapidly with increasing strain, exceeding ten percent of the indicated strain for strains greater than about 0.002 for all tests at room temperature and 900° F. The shape of the curves would indicate that the strain is not being transmitted to the gage properly or that the compensating arms of the gage are being strained a proportionately greater amount as the strain increases. Tests were discontinued at strains of about 0.003.

4.4 Drift

Records of the change of gage output with time for three gages at constant test temperatures up to 1200° F are shown in figures 13 through 19. The results were obtained after heating the gage installation at about 10° F per second from room temperature or the next lower test temperature. Recording was started one minute after the desired test temperature was reached. The second series of tests, Run 2, were made after the gages had been tested once at each test temperature up to 1000° F. The temperature fluctuations during the tests exceeded 3° F during only one test of one gage during the second test series at 800° F. The data was not corrected for temperature fluctuations.

The results indicate that the gages are well compensated for resistance instability effects which did not exceed 2×10^{-3} for 30 minutes to 1200° F. At temperatures up to 1000° F, the greatest average drift rate for thirty minutes was less than 10^{-5} per minute (apparent relative resistance change of one gage arm). This is equivalent to an apparent strain of about 3×10^{-6} per minute.

4.5 Temperature Sensitivity

Average values of the change of gage output with increasing temperature for three gages are shown in figures 20 through 22. The maximum and minimum values obtained during the tests are also shown. During these tests, the gages were heated at about 10° F per second. Tests 1 and 2 were carried to a maximum temperature of about 1000° F. Tests 3, 4 and 5 were carried to a maximum temperature of about 1600° F. Results are shown for tests 1, 3 and 5 only since the values for tests 2 and 3 were in good agreement at temperatures up to 1000° F, and the values for tests 4 and 5 were in good agreement for temperatures up to 1600° F. Each point on the graphs was determined as the slope of a line drawn tangent to a curve of gage output versus temperature. Results for a portion of the fifth test were lost when the x-y recorder went off scale.

4.6 Transient Heating

The results of tests in which the temperature of the test strip to which the gage was attached was increased at about 2°, 10°, 25°, 50° and 80° F per second are shown in figure 23. The results of all tests are not shown because the differences between tests at the same heating rate were not thought to be

significant after the first test. Tests were also made with no power to the gage circuit to determine the possible effect of uncompensated thermal emfs within the circuit. Results of these tests indicated that the effects, if any, are small.

The results shown in figure 23 indicate that these gages are quite sensitive to heating rate, at least when radiant heating techniques are used. This is probably due to the poor thermal contact between the gage shim material and the test strip at the outer edge where the compensating arms of the gage are located and the intimate contact created by the spot welds along the center line near the active arms. This difference in contact with a heat sink (or source) and the low thermal conductivity of the shim material could produce large thermal gradients in the gage when high heating rates are encountered.

4.7 Leakage Resistance

Typical results of tests to determine the resistance between the gage and the test strip as a function of temperature are shown in figure 24. The results were recorded while the test strip was being heated at a rate of about 10° F per second to the maximum test temperature. Two tests to a maximum temperature of about 1000° F were followed by three tests to about 1600° F. Four gages were tested, but, since the results were nearly the same for all gages, the results for only one gage are shown. These results show that, even though these gages have been post cured during their manufacture, there is considerable improvement in the leakage resistance after the first heating cycle to 1000° F. Further improvement is found after heating the gages to 1600° F. The values shown can be considered to be only a qualitative indication of the insulating properties of the cement since it has been found that ceramic cements do not follow Ohm's law (reference 17). The small negative leakage resistance shown at higher temperatures is probably due to an emf being generated between the test strip material and the gage element.

5. CONCLUSIONS

For gages of this type, the data obtained from the evaluation tests covered by this report indicate that:

(1) Gage factor values for compression loading were, on the average, about five percent higher than for tension loading. For both modes of loading, the gage factor varied as much as ± 10 percent from the manufacturer's value.

(2) The gage factor decreases in a linear manner with increasing temperature to 1000° F. At 1000° F the value is about five percent below the value at room temperature.

(3) At strains of 0.002, errors of indicated strain exceeded ten percent at room temperature and at 900° F.

(4) The gages showed an average drift of less than $3x10^{-6}$ inches per inch per minute for 30 minutes at temperatures up to 1000° F. This low value shows good drift compensation by this gage configuration.

(5) The temperature sensitivity did not exceed 11 parts per million resistance change per degree Fahrenheit to 1000° F.

(6) The gages were sensitive to heating rate, at least when radiant heating methods were used.

(7) The resistance between the gage and the test strip depends upon the temperature and the thermal history of the gage. This resistance was greatly increased by heating to 1000° F or higher.

6. MANUFACTURER'S DATA

Correspondence with the manufacturer (reference 18) has revealed that data gathered in their laboratory do not fully agree with the information contained in this report. In particular, their data show:

(1) A gage factor of 3.28 ± 3 percent at strains of 0.001

(2) The compression gage factor being higher than the tension factor by the following amounts:

(a) 1.3 to 3.6 percent at 0.001 strain
(b) 0.6 to 2.4 percent at 0.002 strain
(c) 1.3 percent at 0.003 strain

(3) Maximum error of indicated strain of 2.7 percent at 0.002 strain and 4.7 percent at 0.003 strain.

(4) Zero shifts not greater than one percent for second and third load cycles at any strain level.

It was also indicated that the manufacturer has found that the installation of the gage is somewhat critical. The installation instructions are said to have been revised to provide the user with better instructions than were previously available. Improvements in manufacturing techniques since the initial release of these gages are also claimed.

As noted in the foreword of this report, and previous reports of this series, strain measurement at elevated temperatures is not a static field. Improvements in materials, methods of fabrication, and techniques in handling the strain gages may improve gage characteristics significantly. The manufacturers of these gages are continually trying to make such improvements to provide the user with better gages.

The authors gratefully acknowledge the assistance of T. W. Butler, C. H. Melton, M. L. Sundquist, and R. J. Wall in performing the evaluation tests and in preparing this report.

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(16) R. L. Bloss and J. T. Trumbo, "A Method for Measuring the Instability of Resistance Strain Gages at Elevated Temperatures," ISA Transactions, Vol. 2, No. 2 p. 112 (1963).

(17) J. W. Pitts and D. G. Moore, "Development of High-Temperature Strain Gages" NBS Monograph 26, 1961.

(18) Letter from L. J. Weymonth, Baldwin-Lima-Hamilton Corp., dated June 19, 1964.

Table 1 - Number of Gages Tested and Gage Circuit Voltage

Type of test	Number of gages tested	Voltage applied to gage Circuit volts, d-c
Gage factor determination	4	6
Gage factor variation	4	6
Large strain	4	3*
Resistance instability (drift)	3	8
Temperature sensitivity	3	8
Transient heating	4	8
Leakage resistance	4	10**

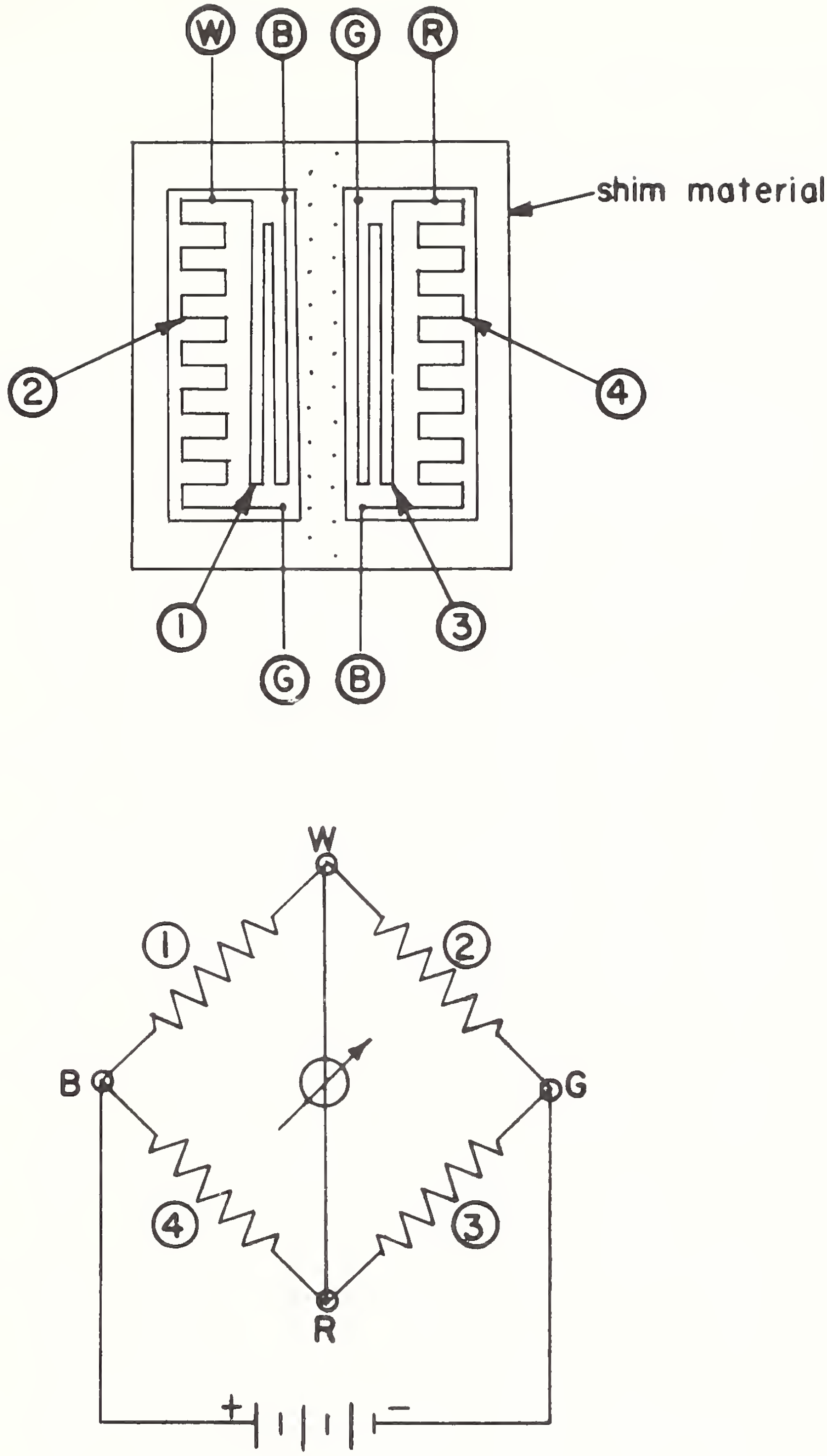
* a-c (1000 cps)
** Maximum voltage between gage and test strip

Table 2 - Heating Rates for Transient Heating Tests

Test No.	Nominal heating rate °F/sec	Power to gage circuit
1 through 3	10	yes
4 through 6	2	yes
7	10	yes
8 through 10	25	yes
11	10	yes
12 through 14	50	yes
15	10	yes
16 through 18	80	yes
19	10	yes
20	10	no
21	50	no
22	80	no
23	10	no
24	50	no
25	80	no

Table 3 - Gage Factor Values at Room Temperature (Approximately 75° F)

Gage No.	Run No.	Tension K_u	Tension K_d	Tension $\bar{K}$	Compression K_u	Compression K_d	Compression $\bar{K}$
A_1	1	2.996	3.035	3.016	3.026	3.420	3.223
	2	3.169	3.044	3.106	3.238	3.302	3.270
	3	3.149	3.061	3.105	3.283	3.245	3.264
	Average			3.076			3.252
A_2	1	3.132	3.345	3.238	3.384	3.506	3.445
	2	3.356	3.327	3.342	3.525	3.457	3.491
	3	3.374	3.330	3.352	3.440	3.588	3.514
	Average			3.311			3.483
A_3	1	2.742	3.040	2.891	2.820	3.188	3.004
	2	3.106	3.035	3.070	3.035	3.116	3.076
	3	2.959	3.058	3.008	3 039	3.193	3.116
	Average			2.990			3.065
A_4	1	3.000	3.223	3.112	3.156	3.445	3.300
	2	3.289	3.210	3.250	3.330	3.436	3.383
	3	3.243	3.294	3.268	3.336	3.437	3.386
	Average			3.210			3.356



Suggested Wiring Color Code

B-Black R-Red

G-Green W-White

Fig. 1 Gage Configuration and Electrical Circuit

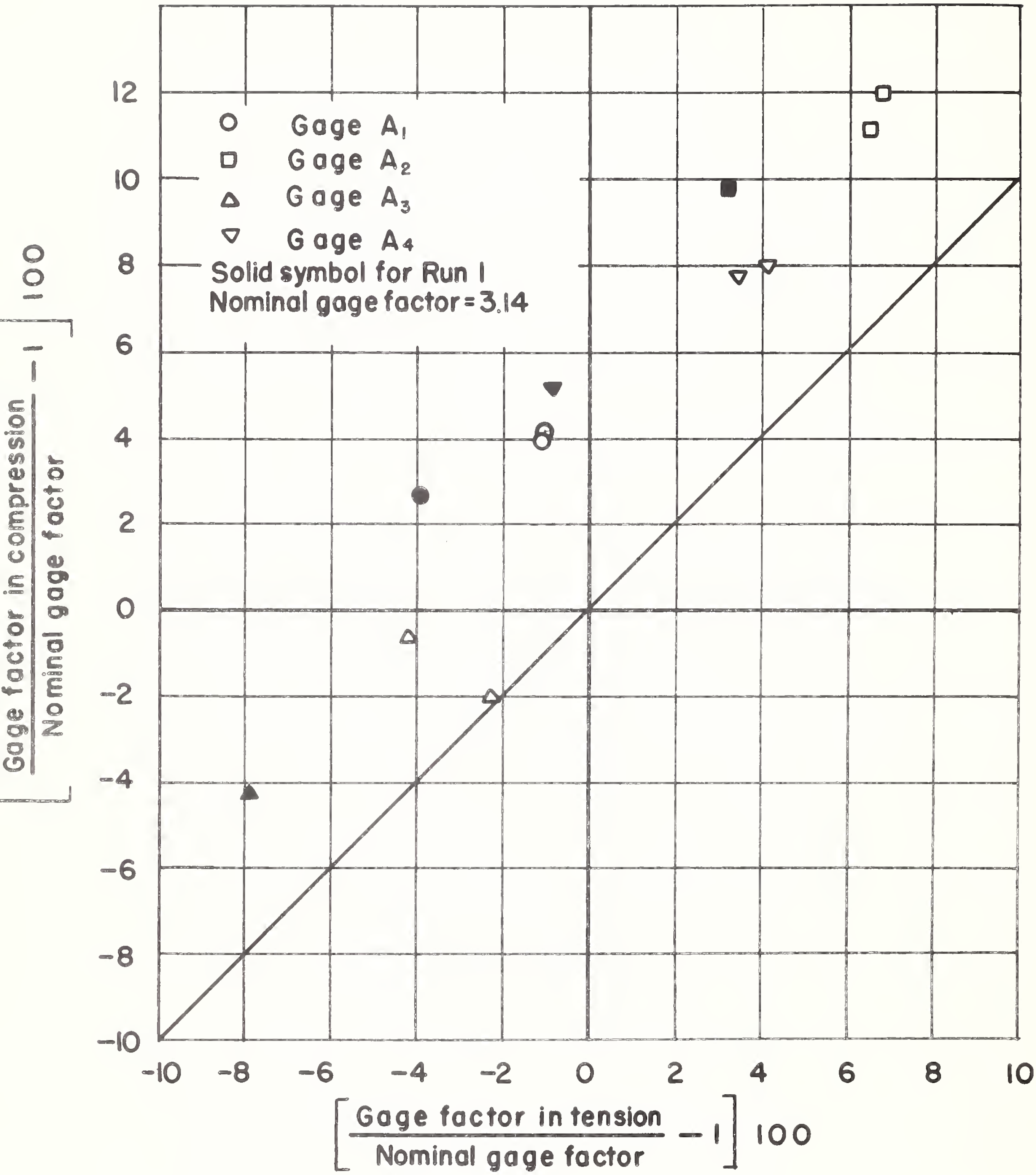


Fig. 2 Gage factor deviation at 75° F

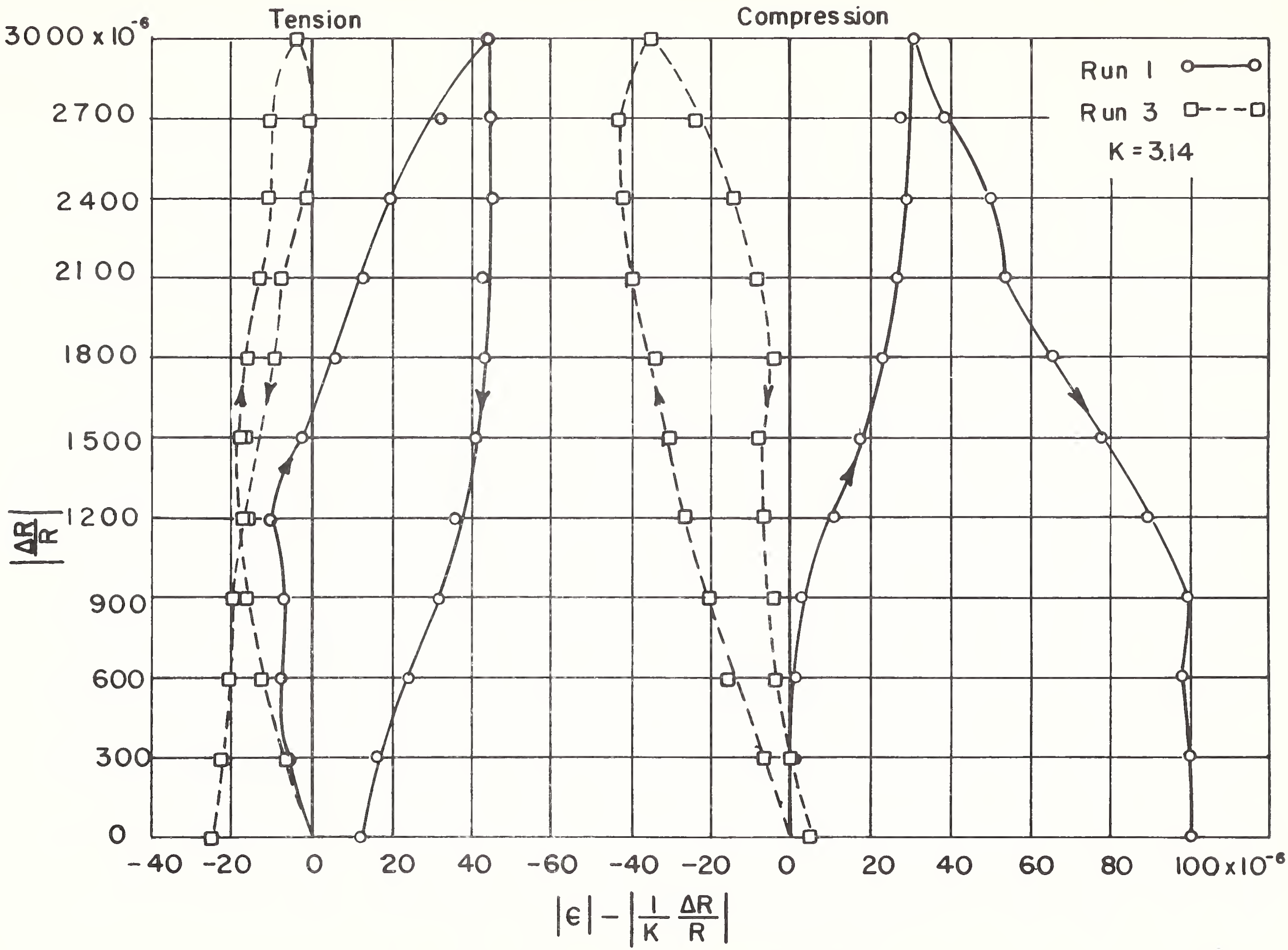


Fig. 3 Strain deviation for gage 2.5-A, at 75° F

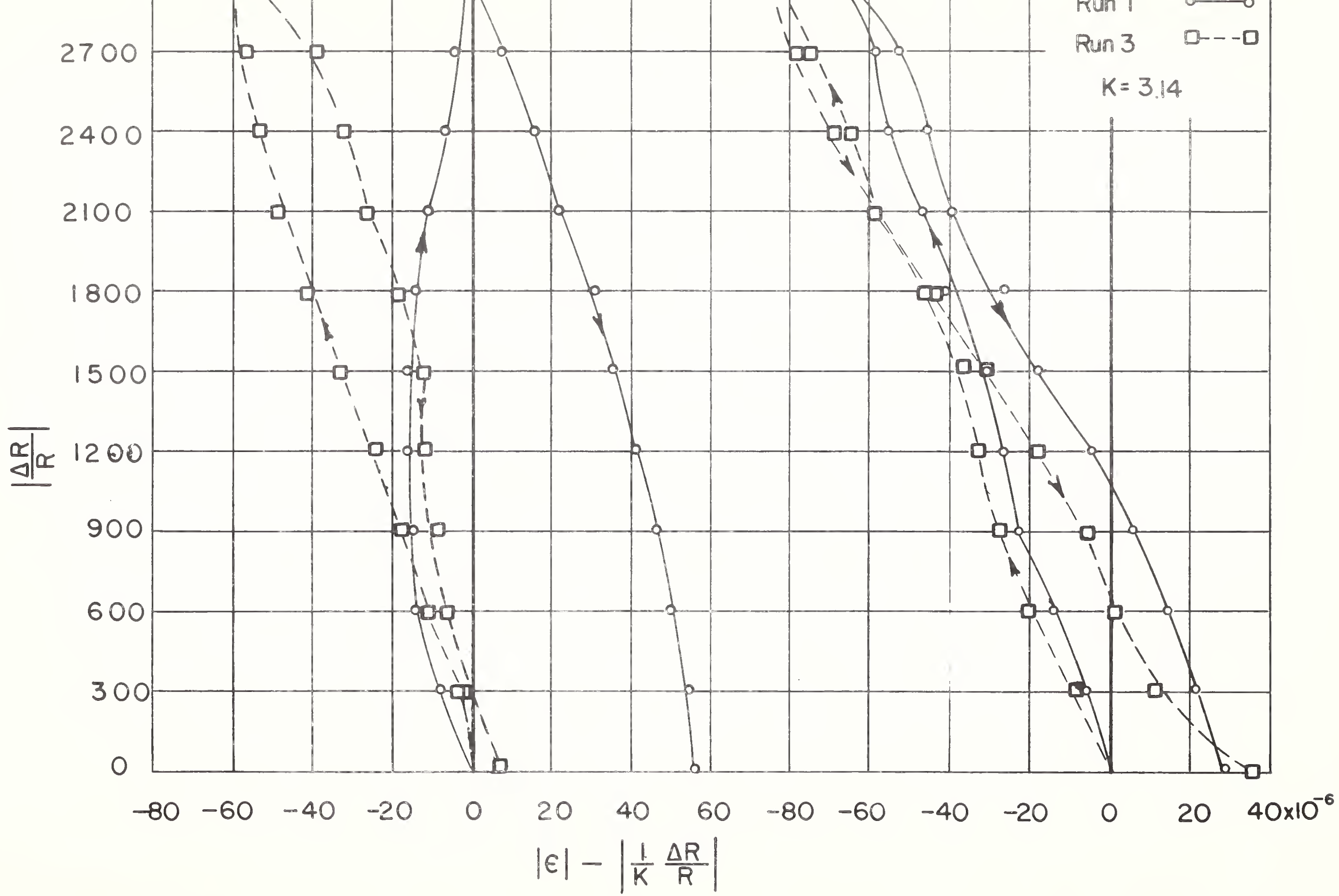


Fig. 4 Strain deviation for Gage 2.5 − A_2 at 75° F

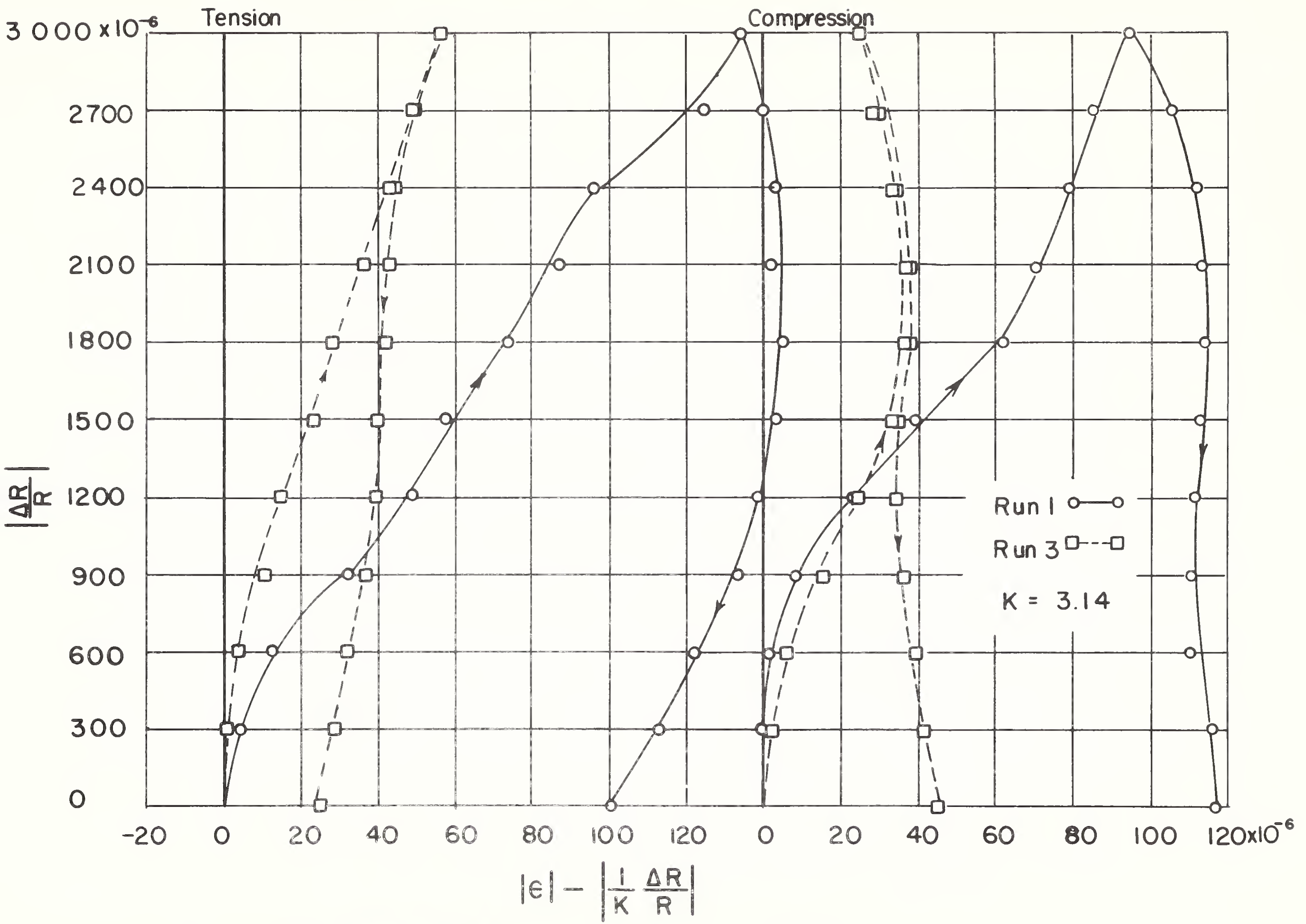


Fig. 5 Strain deviation for Gage 2.5—A at 75° F

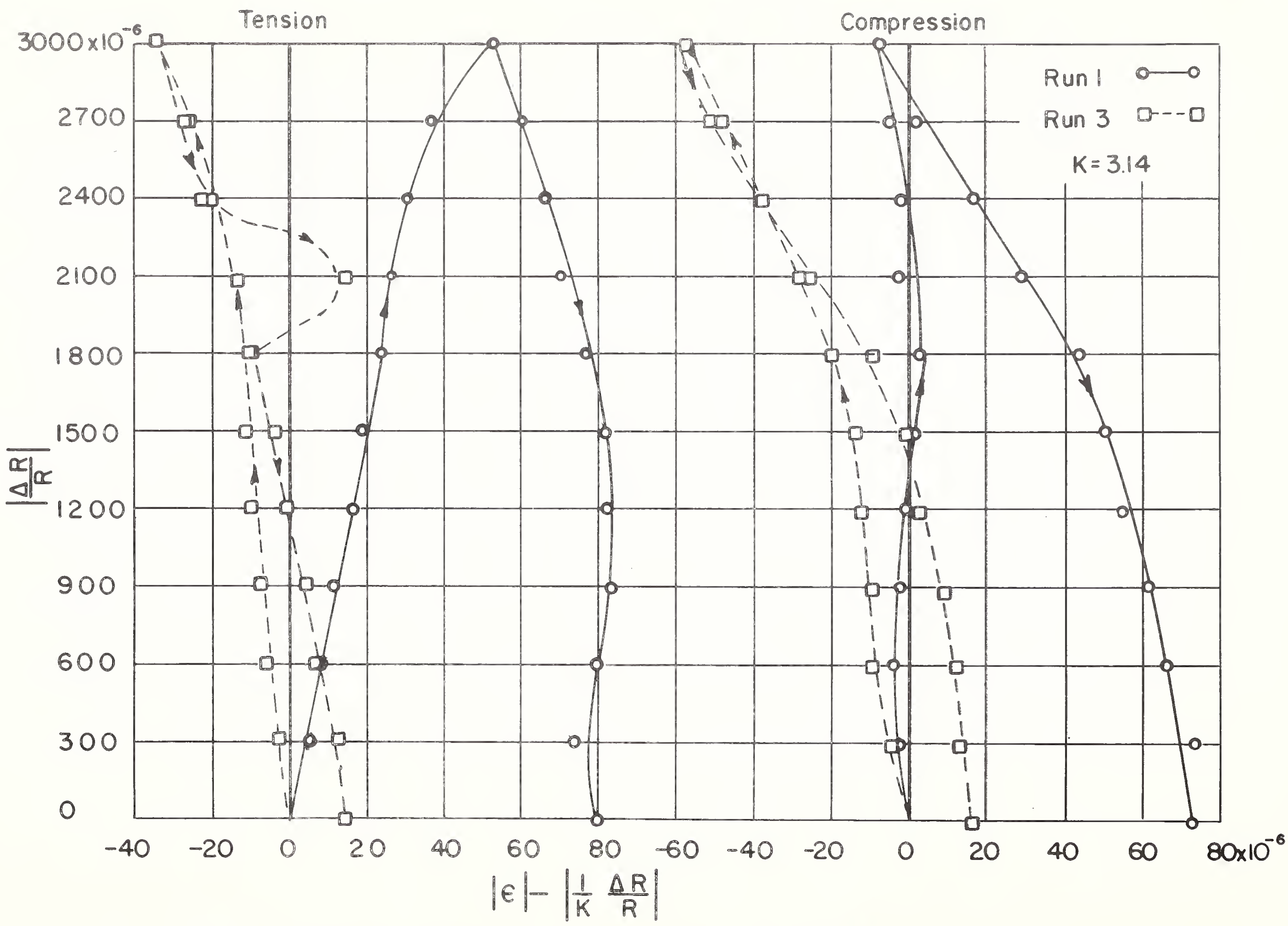


Fig. 6 Strain deviation for Gage 2.5–A_4 at 75° F

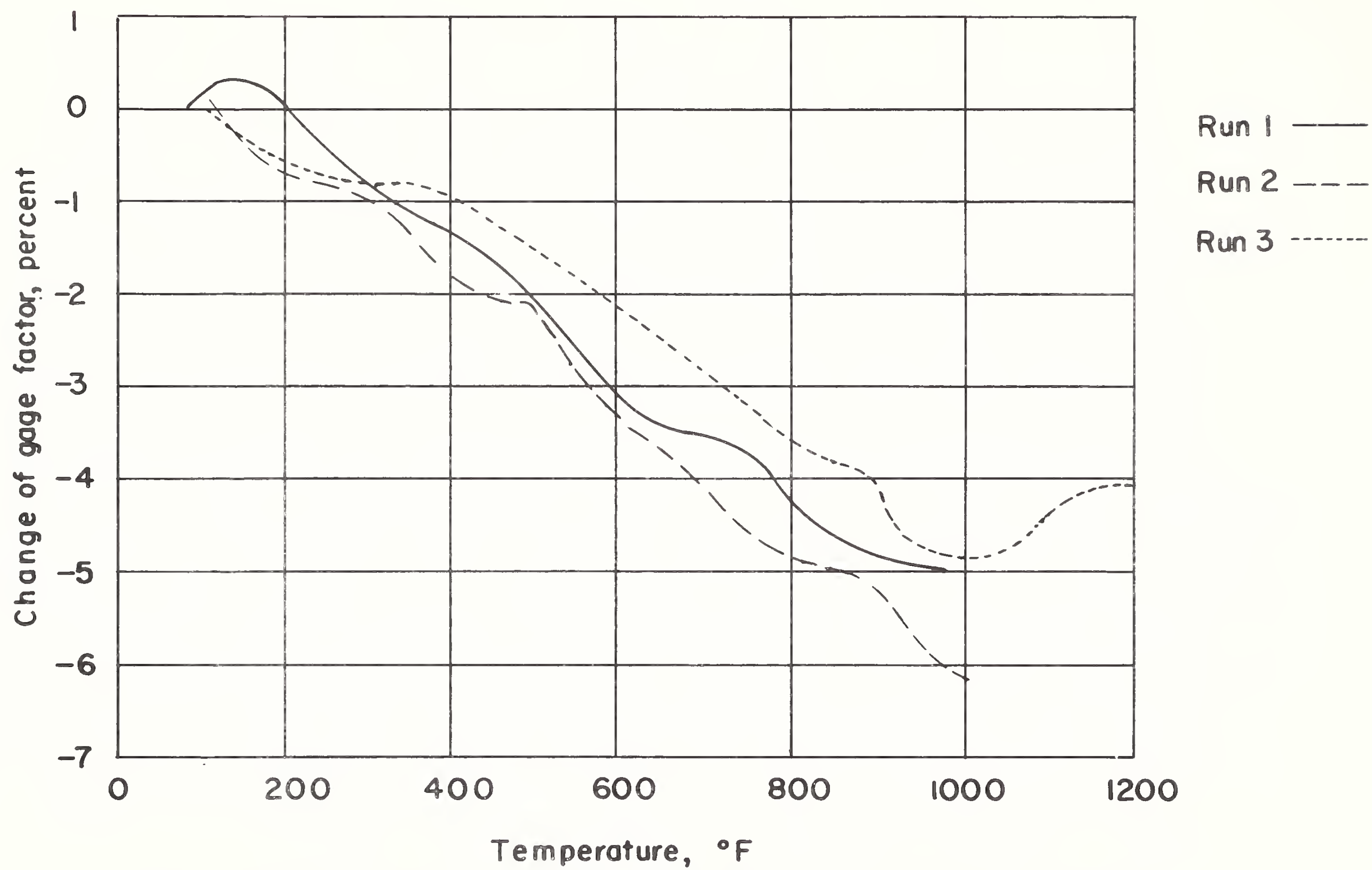


Fig.7 Variation of gage factor with temperature for Gage 2.5-B_2

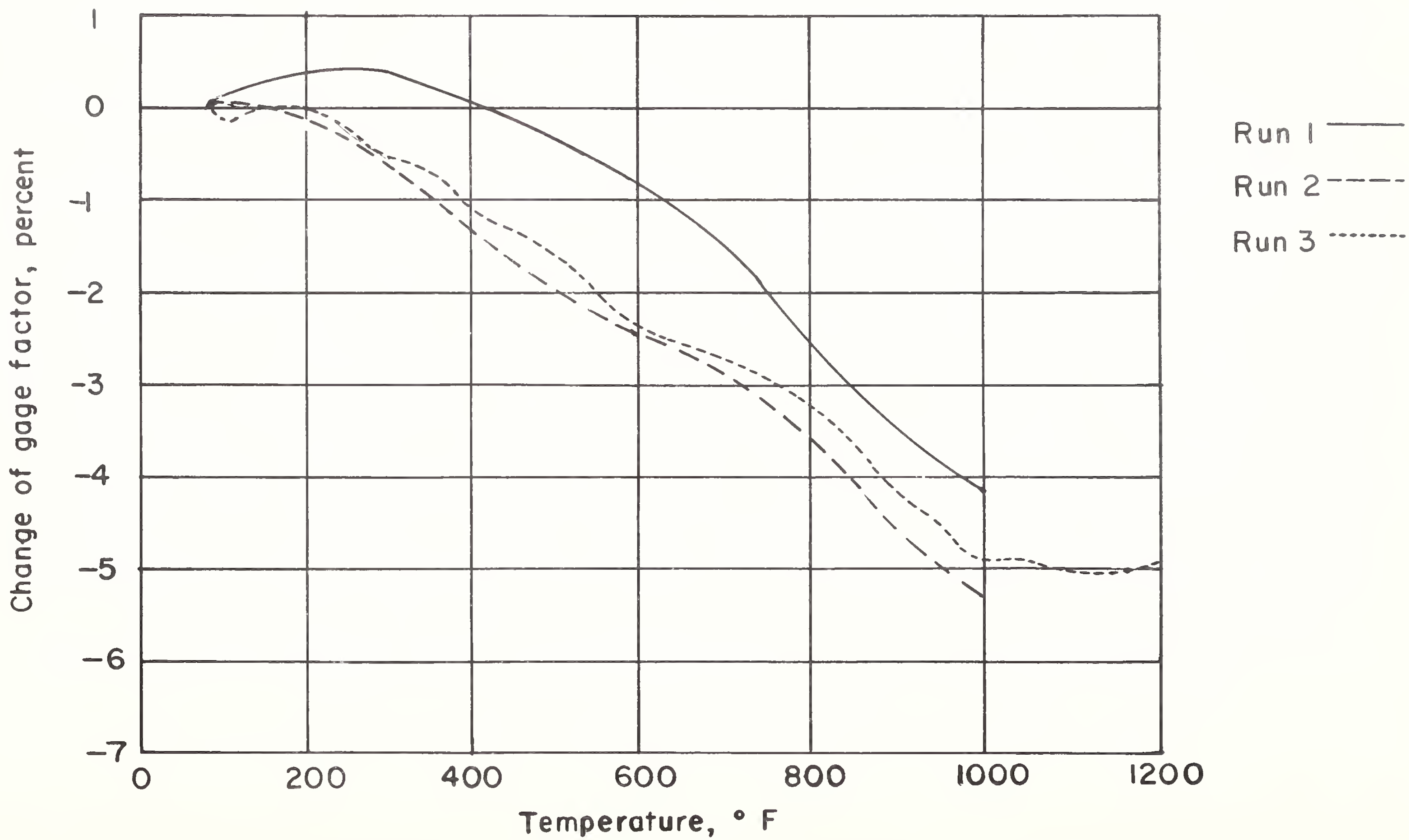


Fig. 8 Variation of gage factor with temperature for Gage $2.5-B_3$

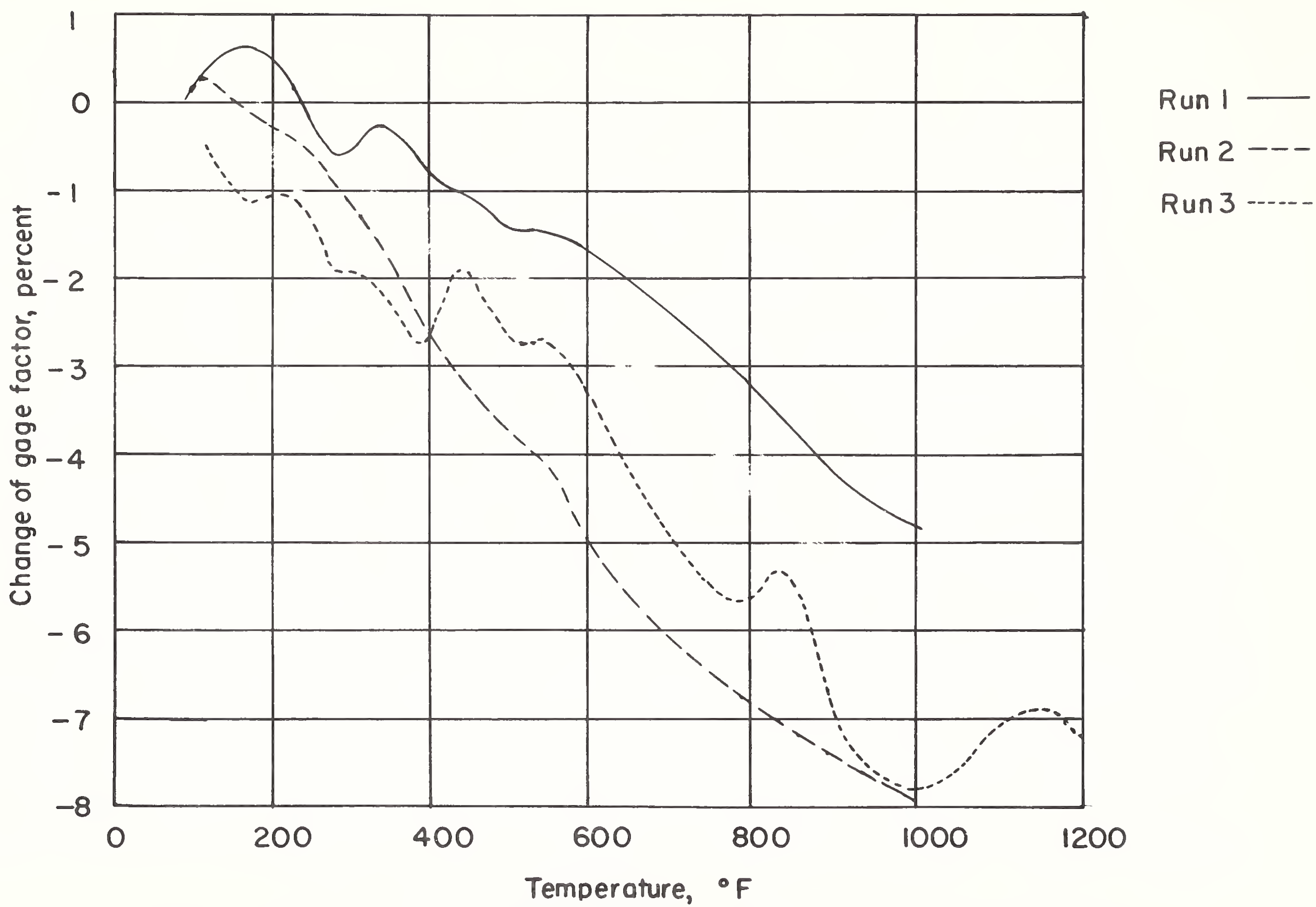


Fig. 9 Variation of gage factor with temperature for Gage 2.5–B_4

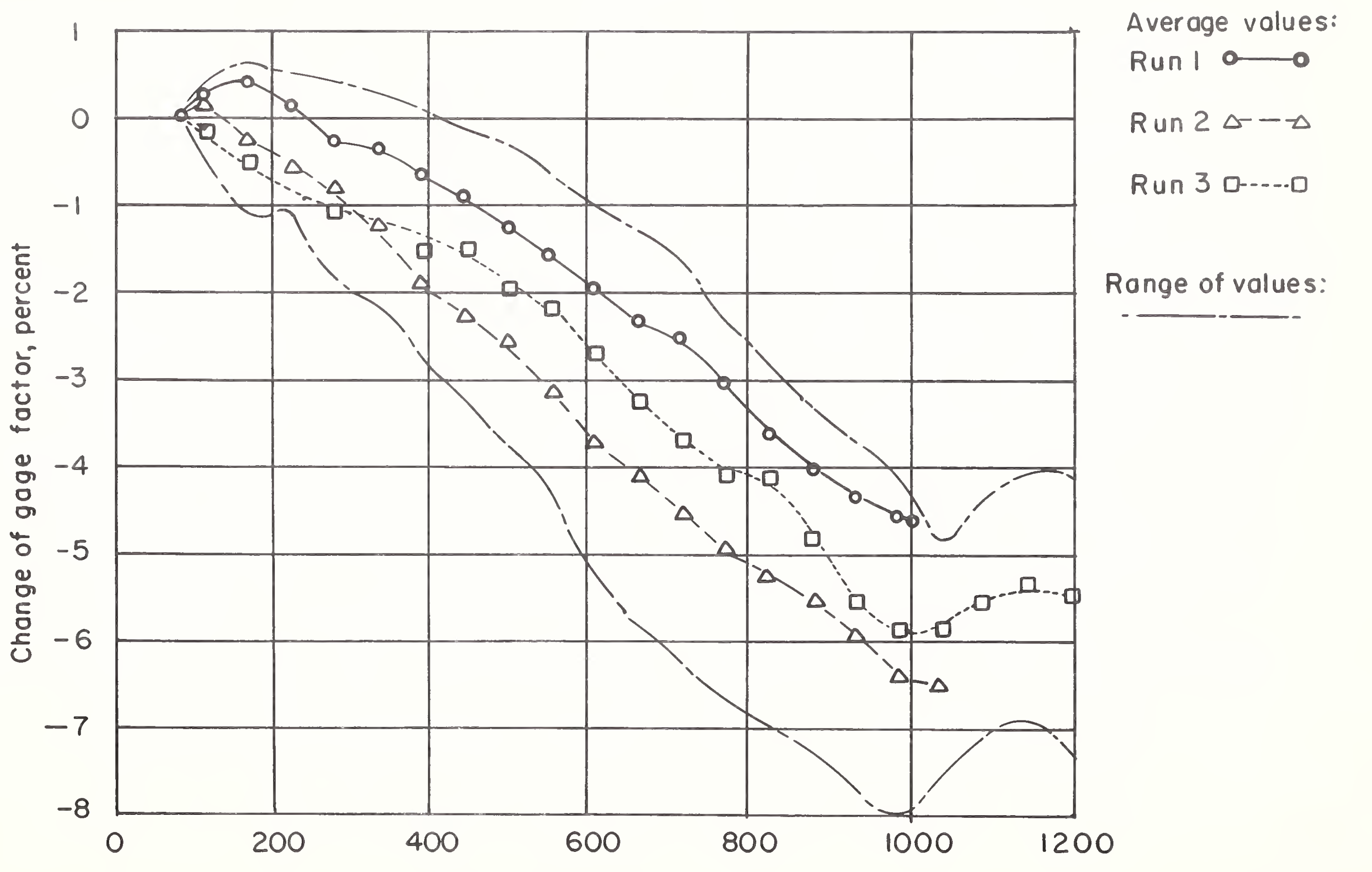


Fig.10 Variation of gage factor with temperature for three gages

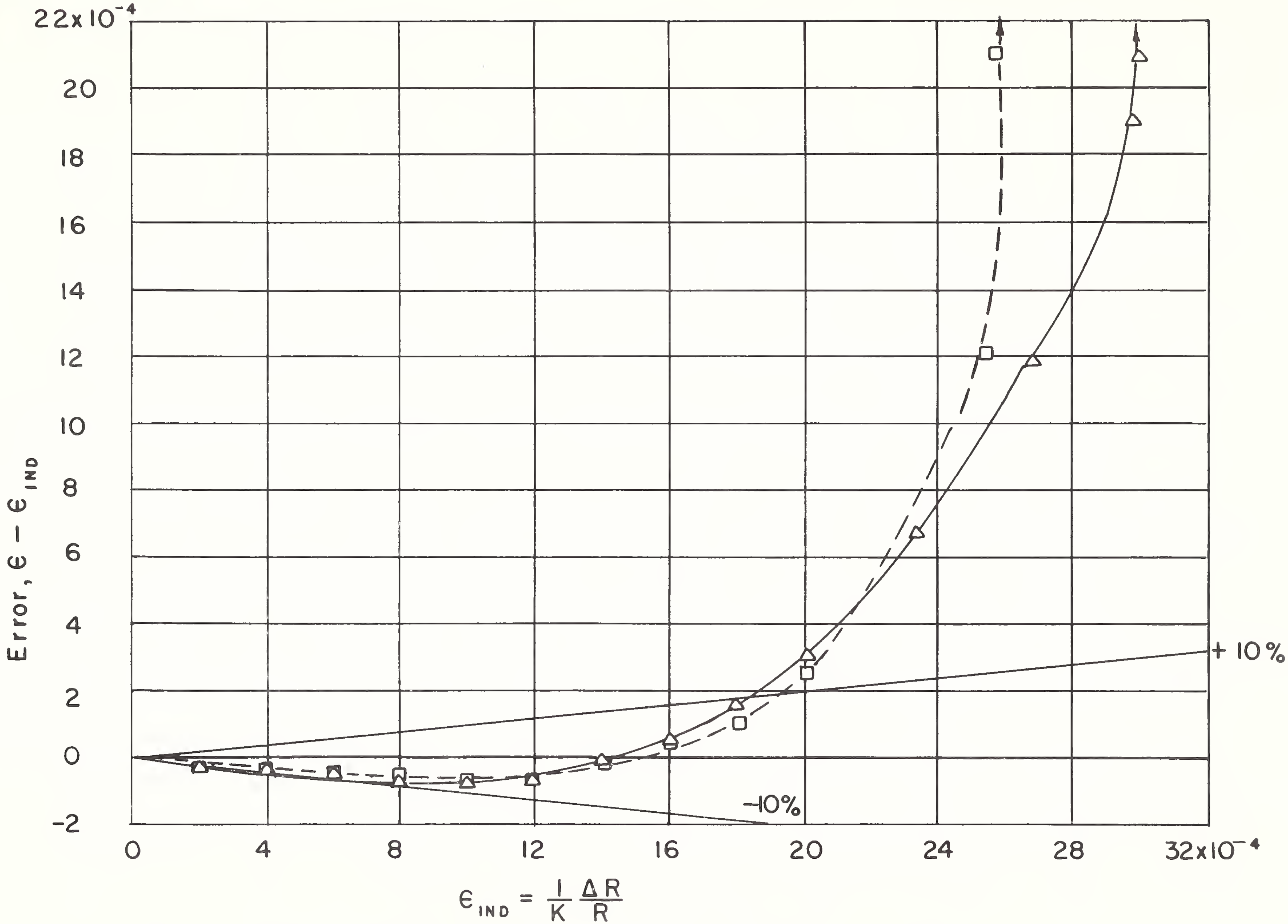


Fig. 11 Behavior of two gages at large strains at 75°F

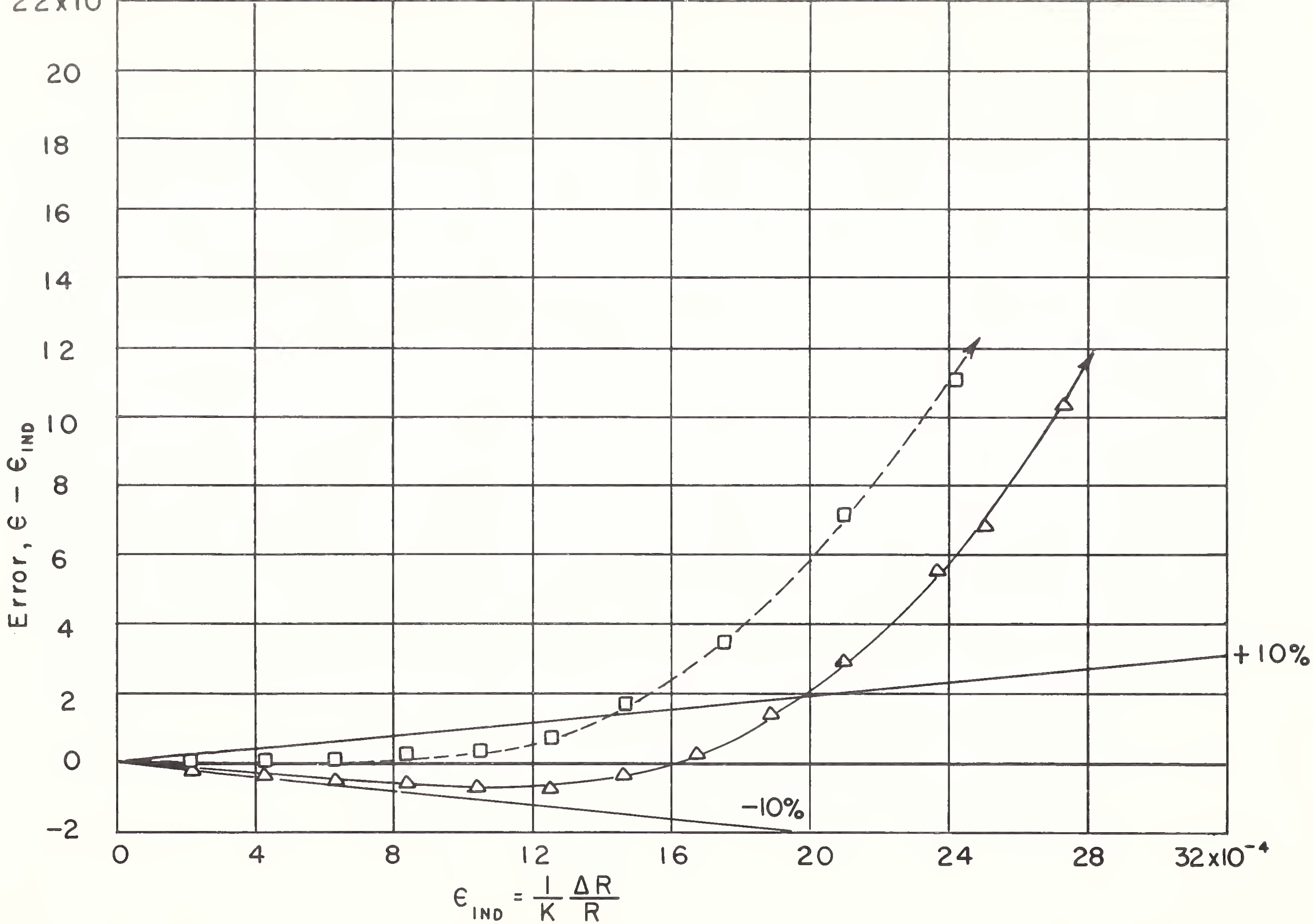


Fig. 12 Behavior of two gages at large strains at 900° F

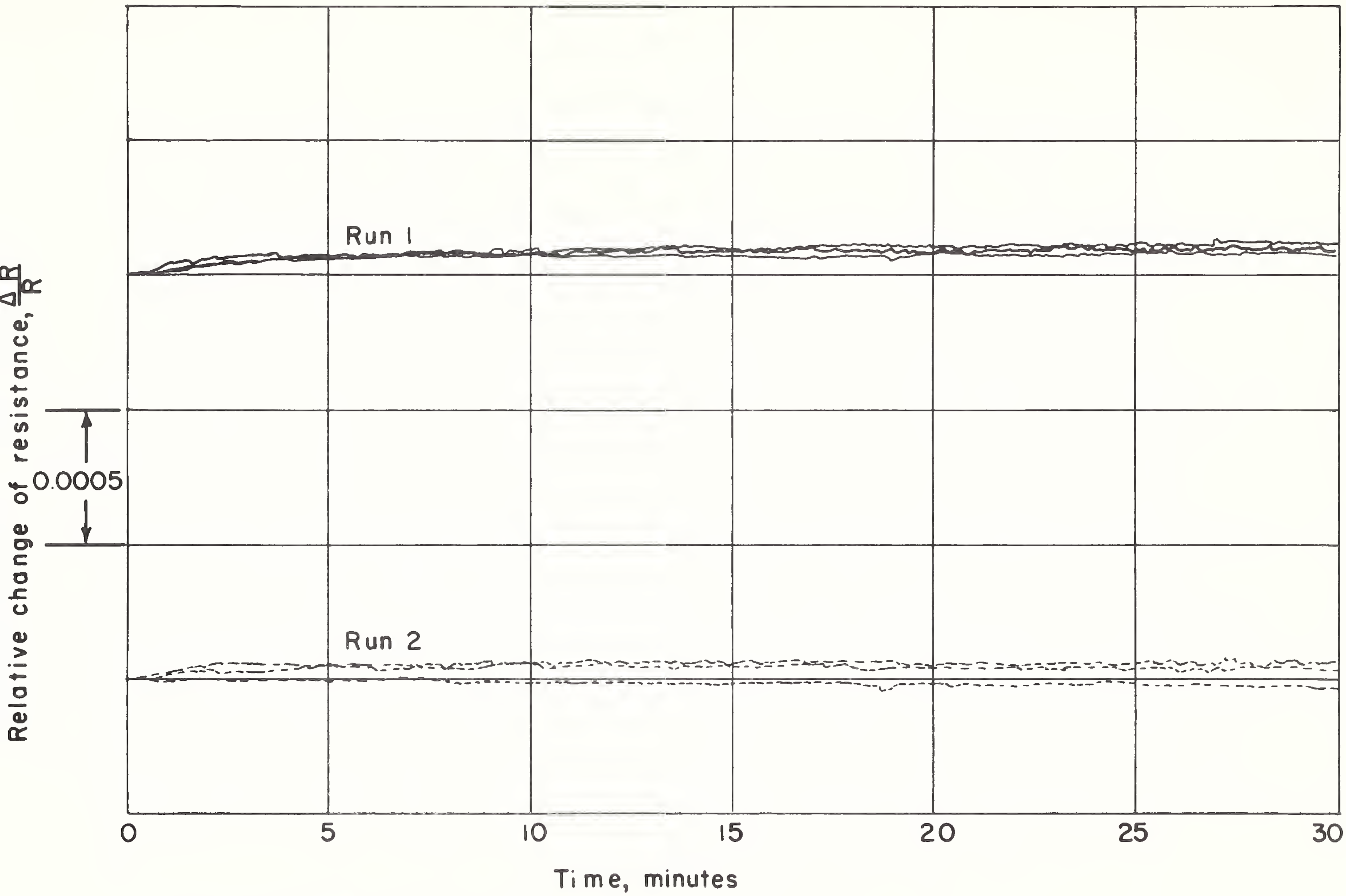


Fig. 13 Drift behavior of three gages at 600 °F

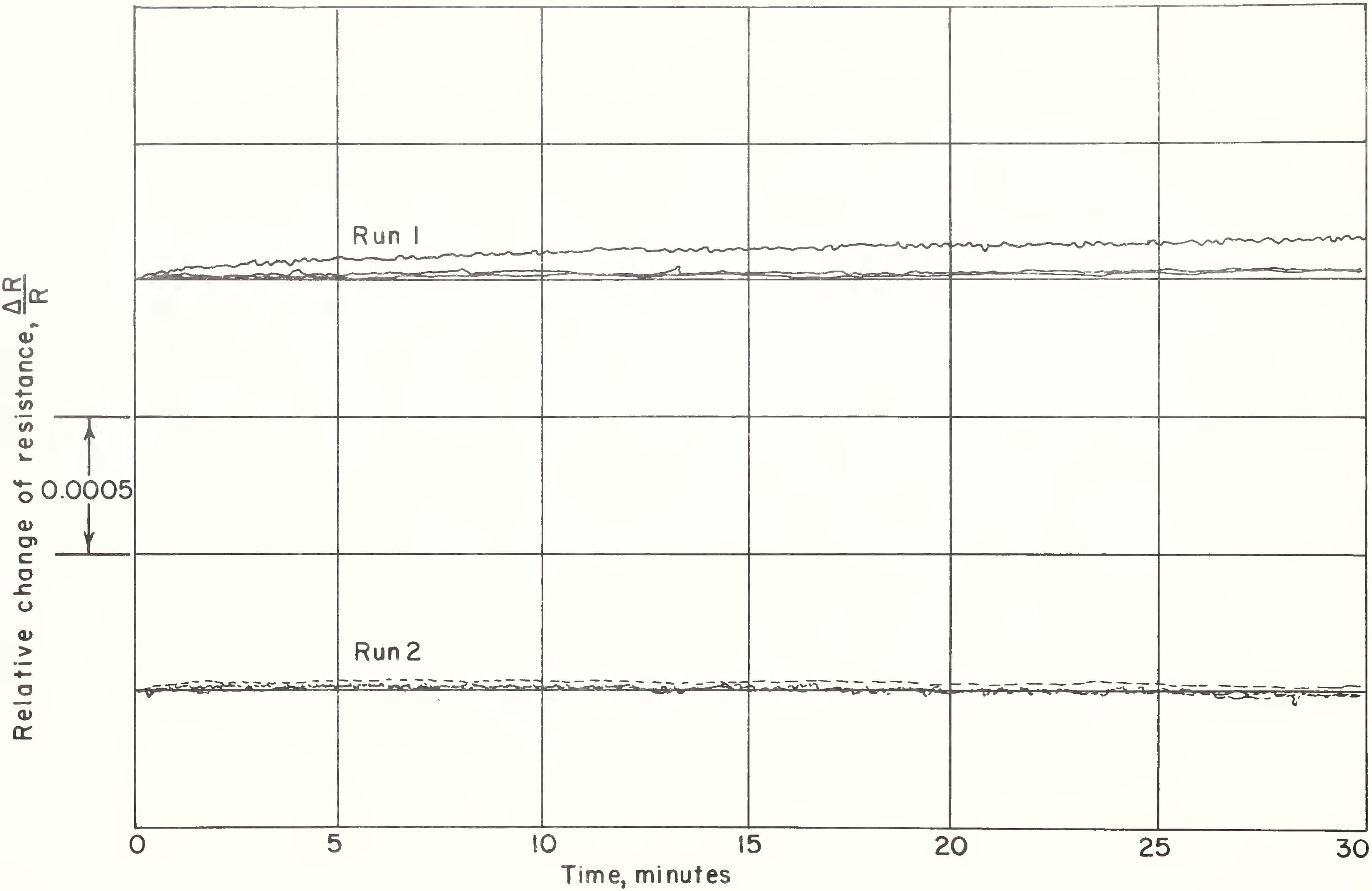


Fig. 14 Drift behavior of three gages at 700° F

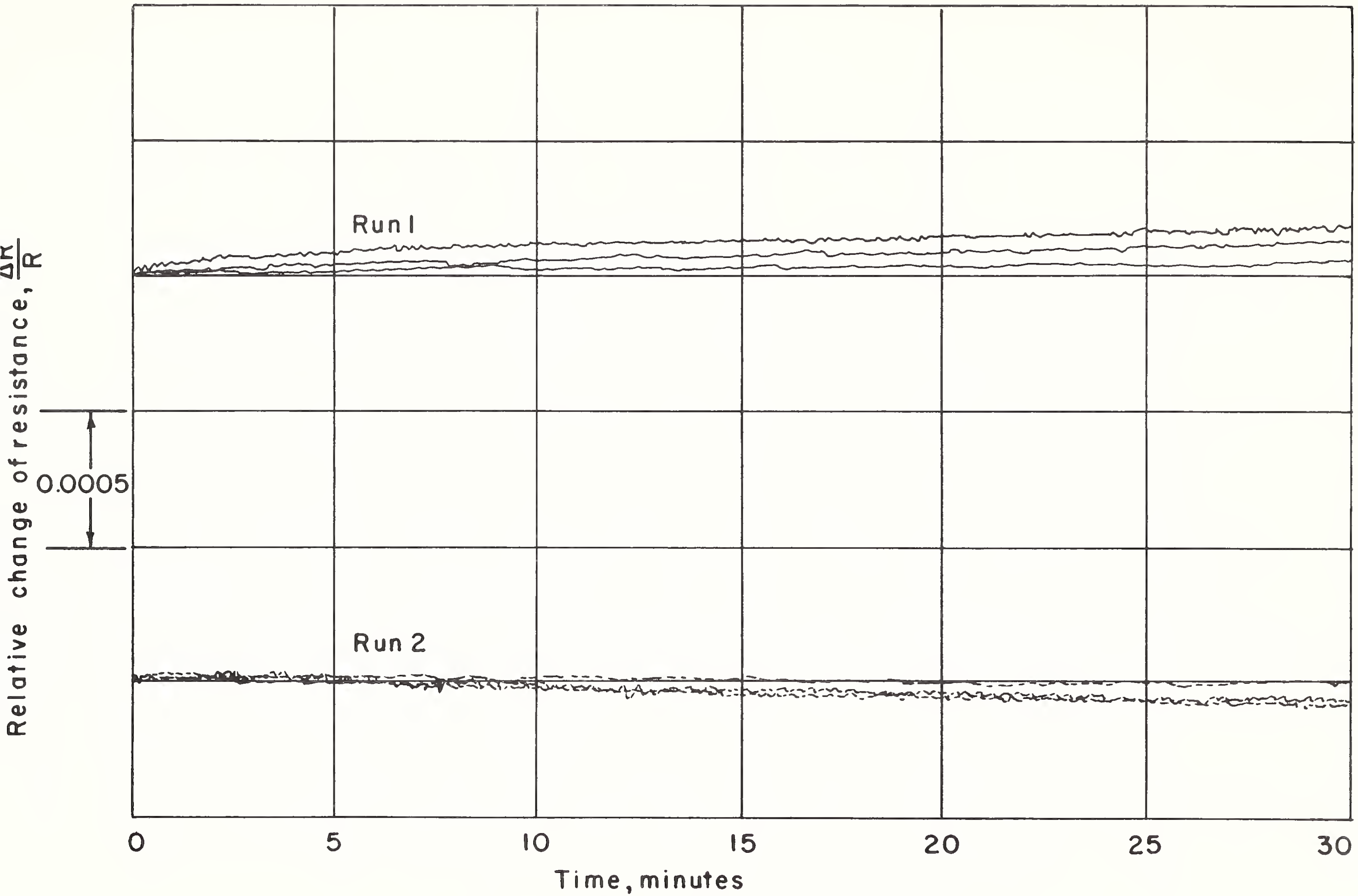


Fig. 15 Drift behavior of three gages at 800° F

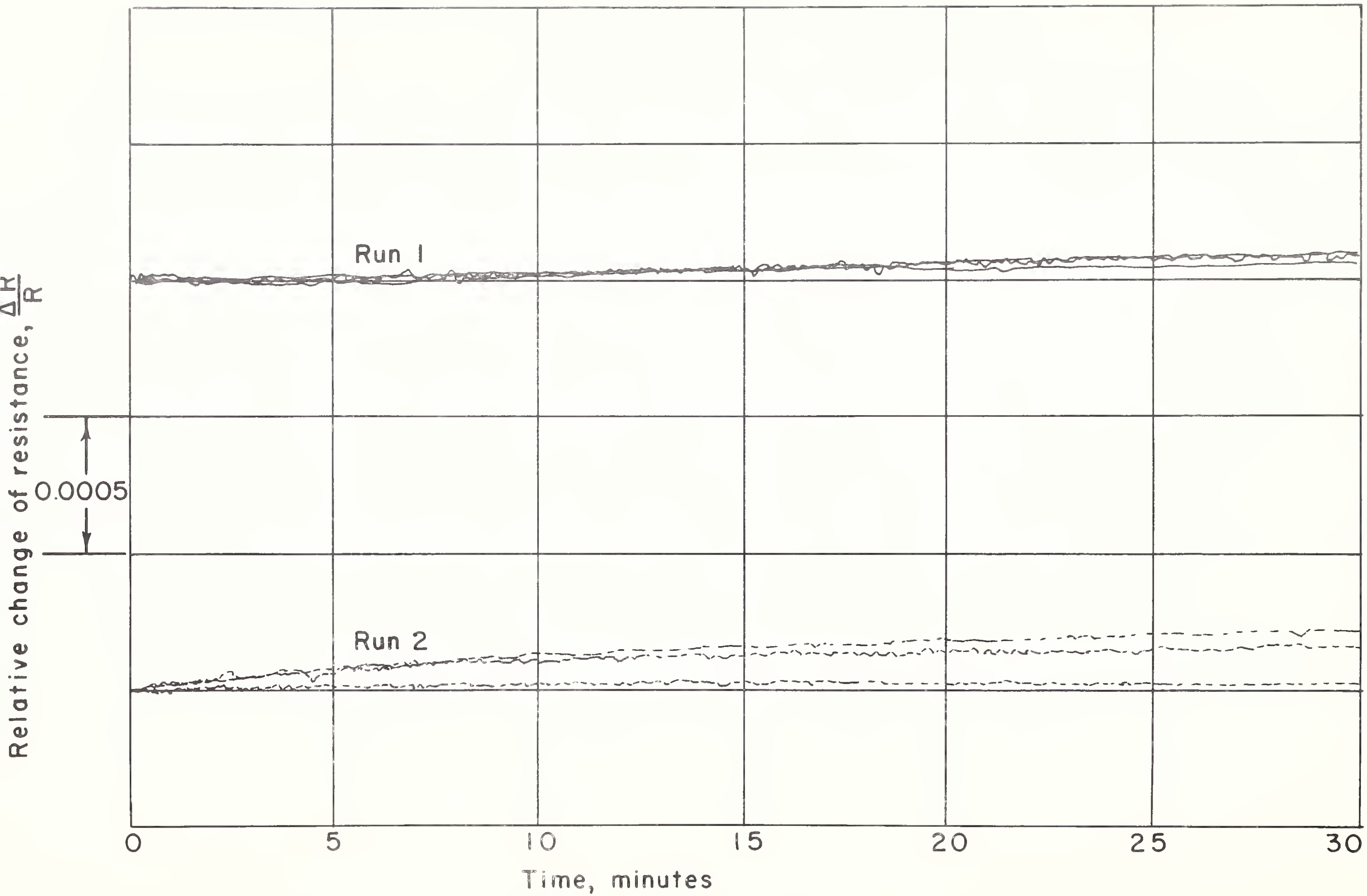


Fig. 16 Drift behavior of three gages at 900 °F

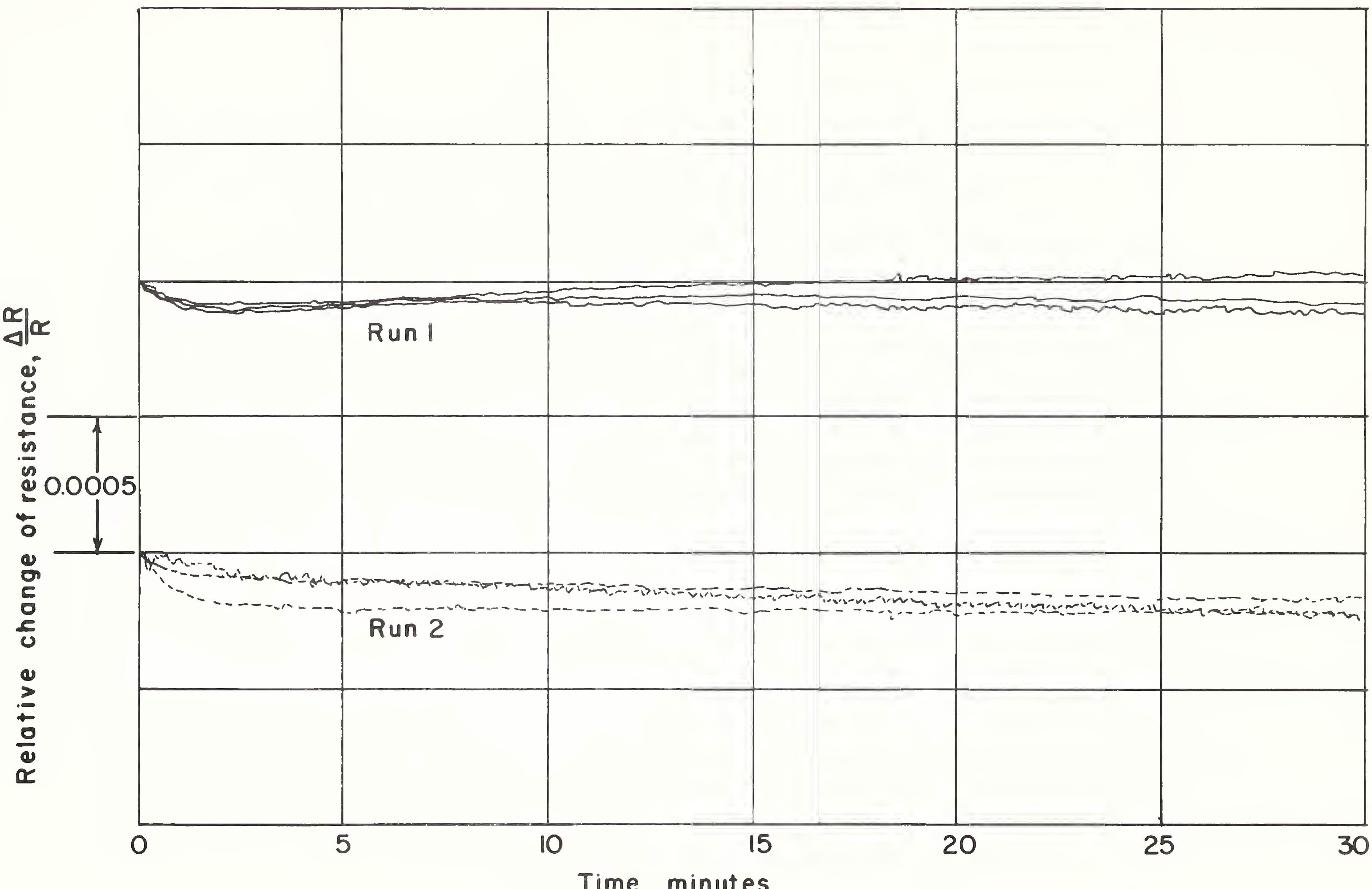


Fig. 17 Drift behavior of three gages at 1000 ° F

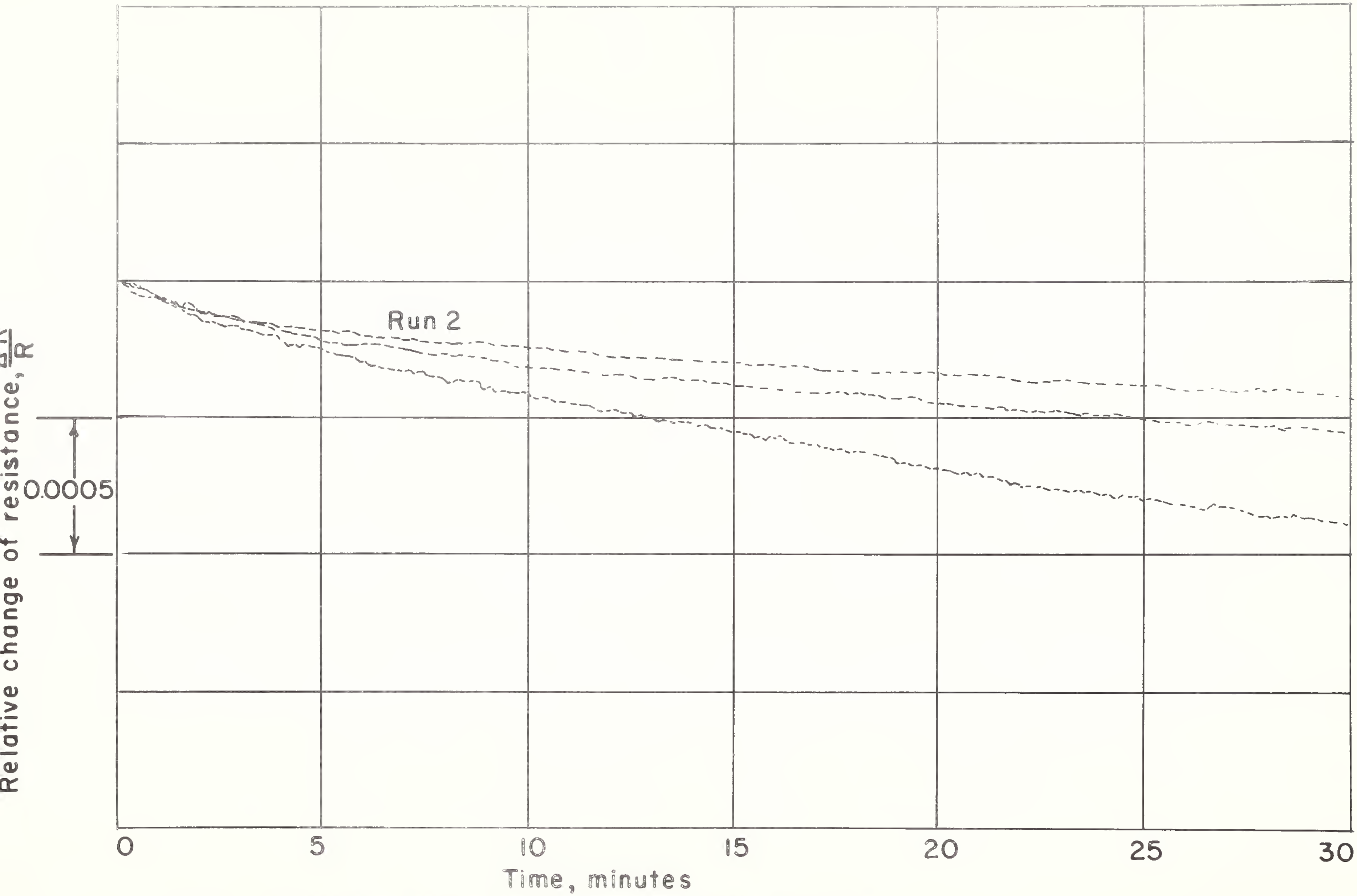


Fig. 18 Drift behavior of three gages at 1100° F

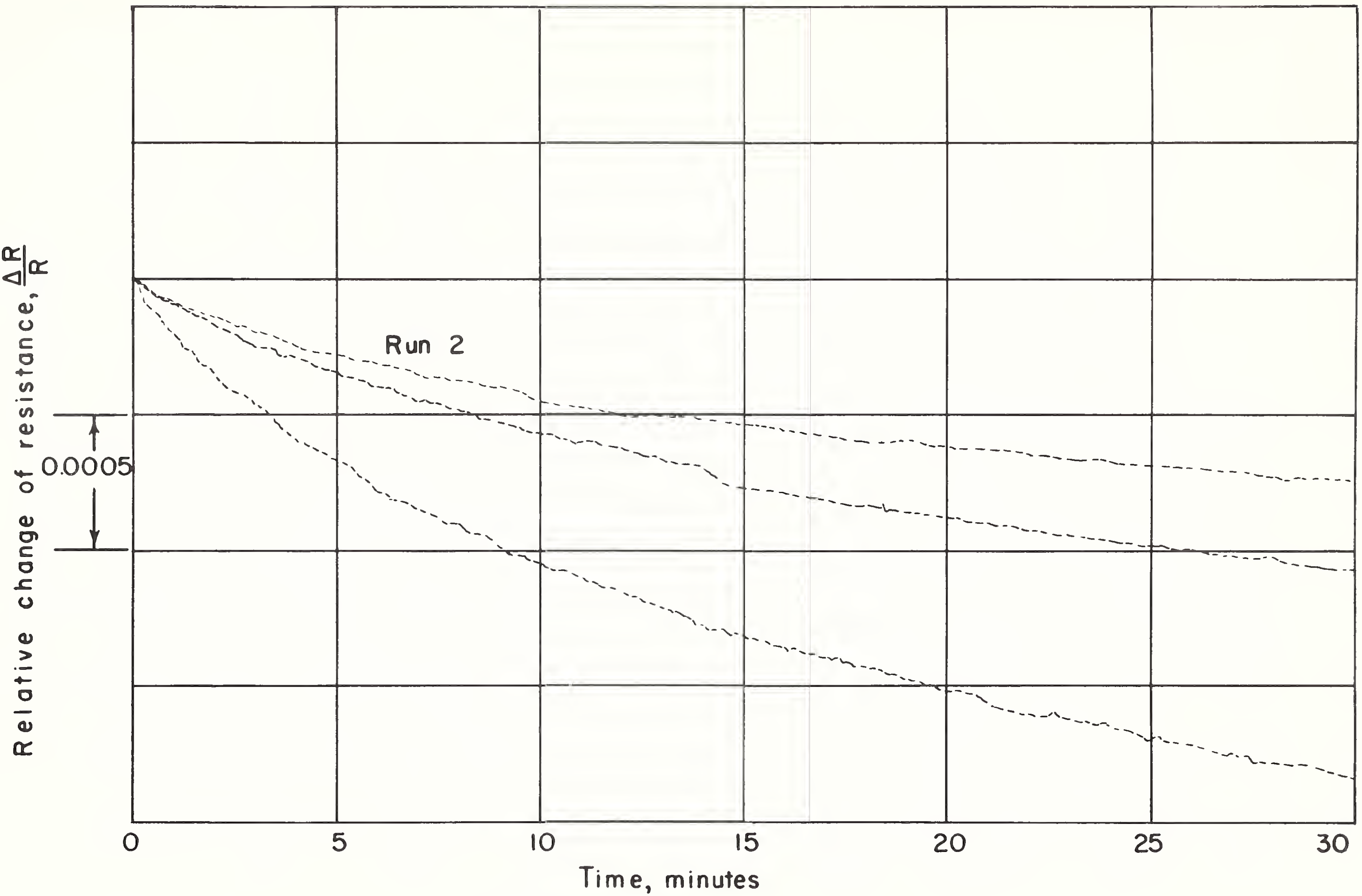


Fig. 19 Drift behavior of three gages at 1200° F

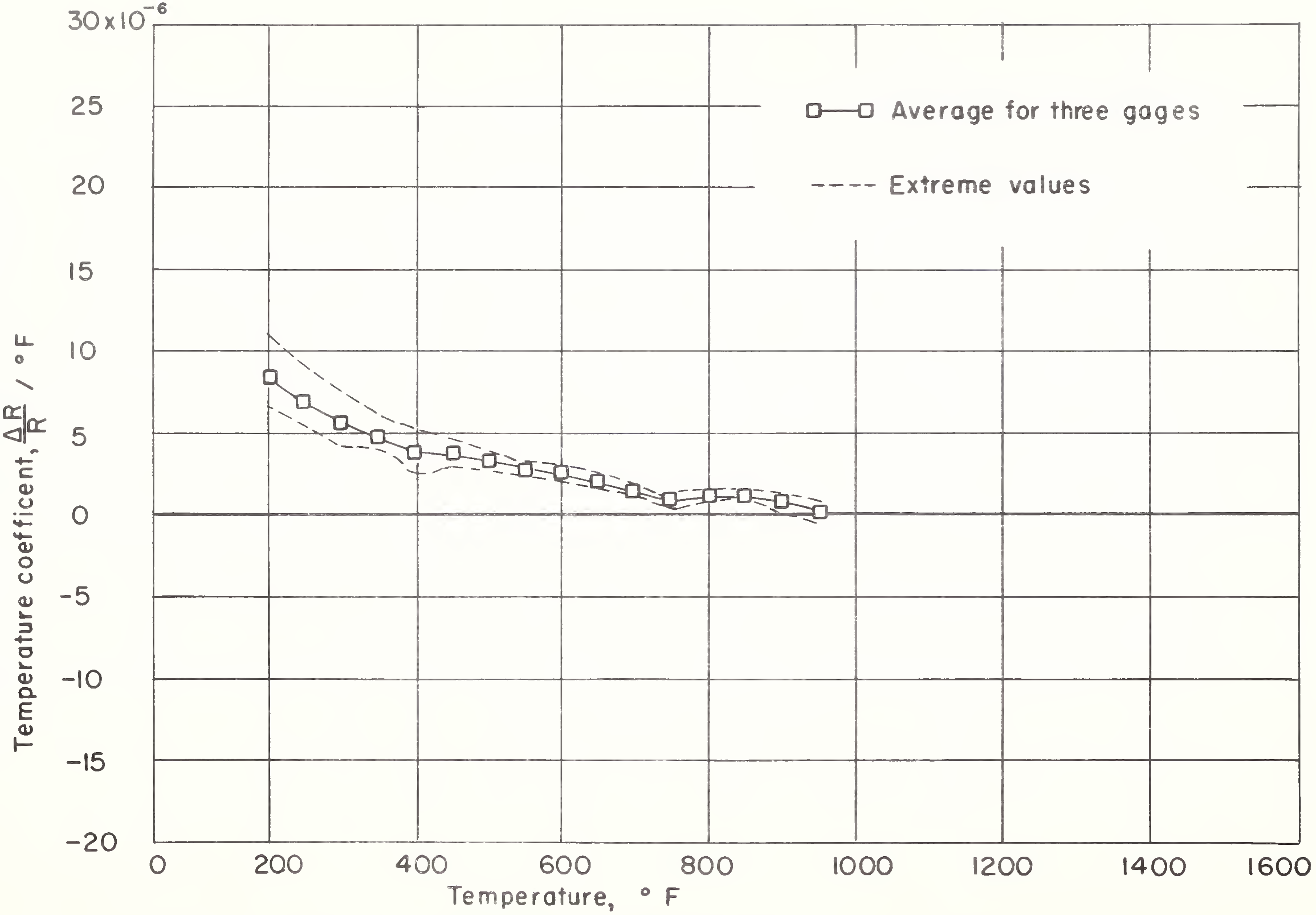


Fig. 20 Temperature sensitivity during first test.

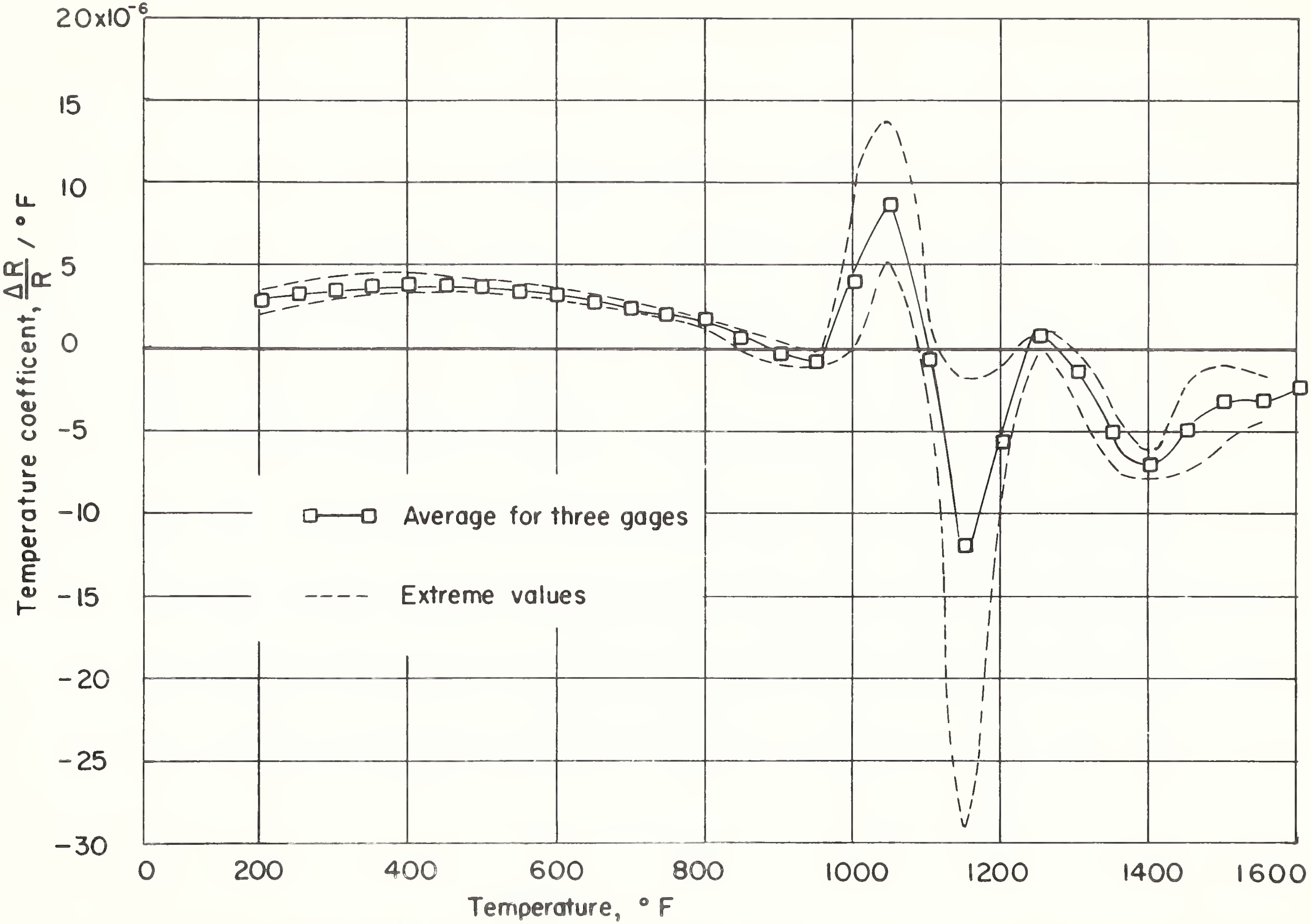


Fig. 21 Temperature sensitivity during third test

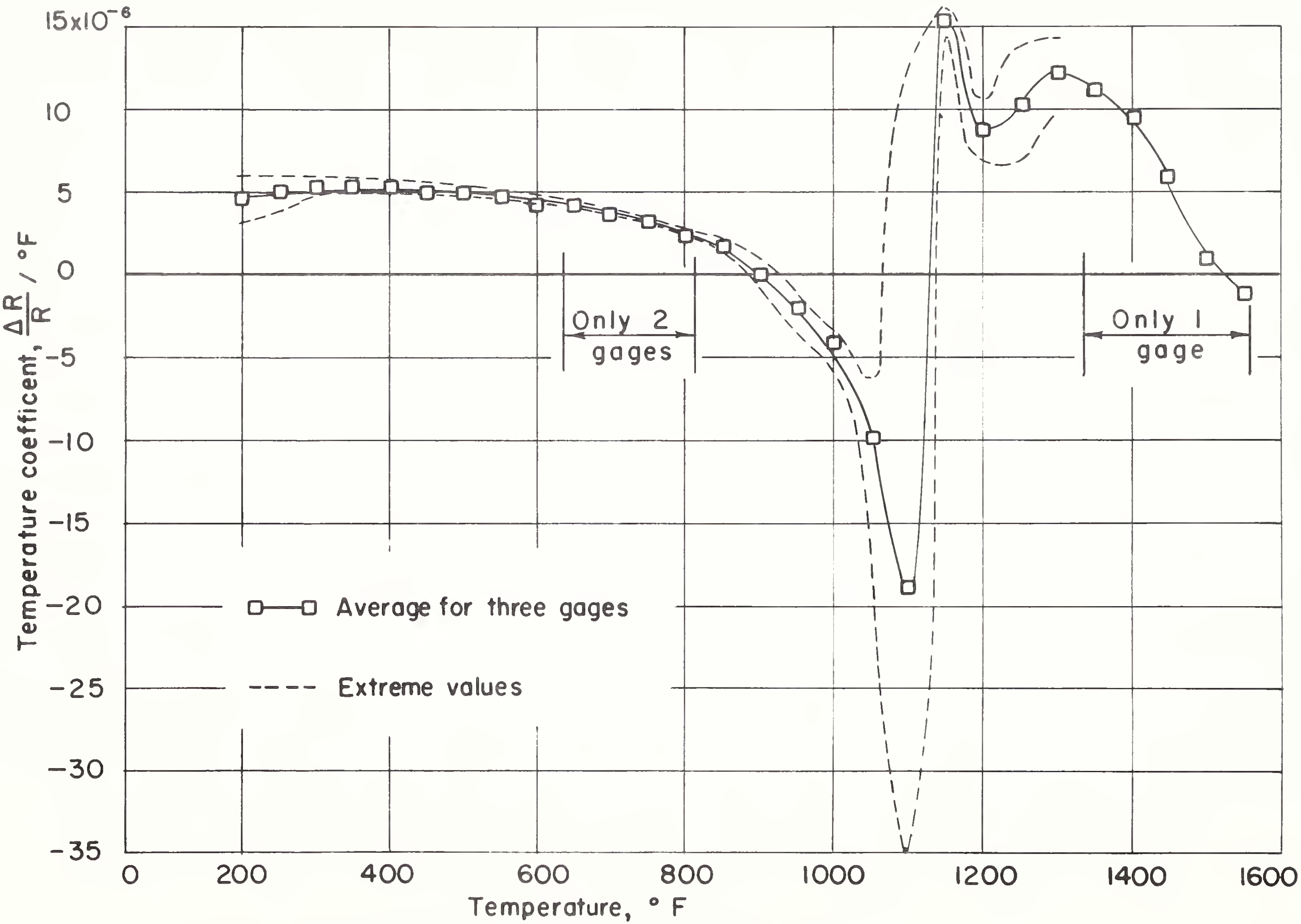


Fig. 22 Temperature sensitivity during fifth test

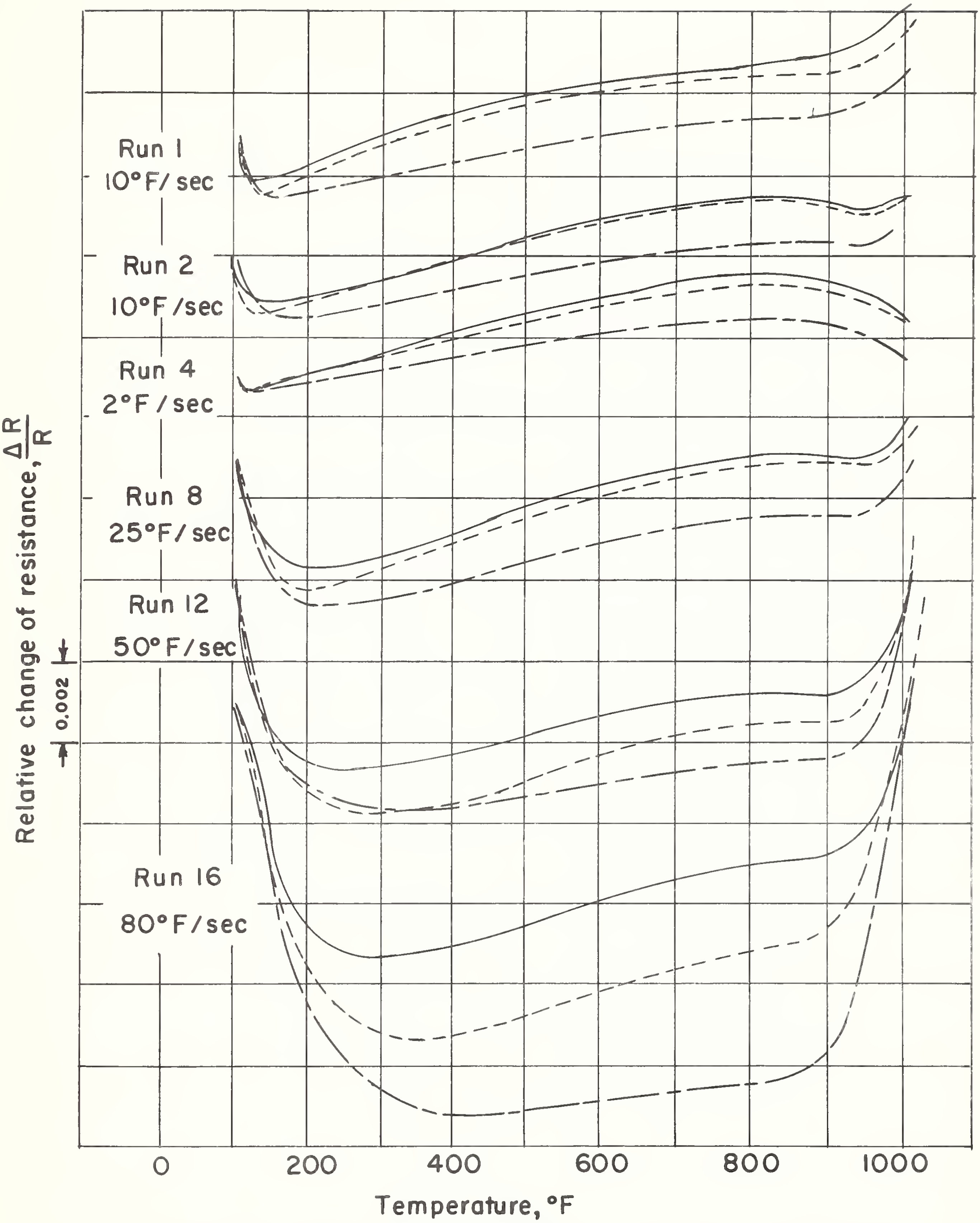


Fig. 23 Response of three gages at various heating rates

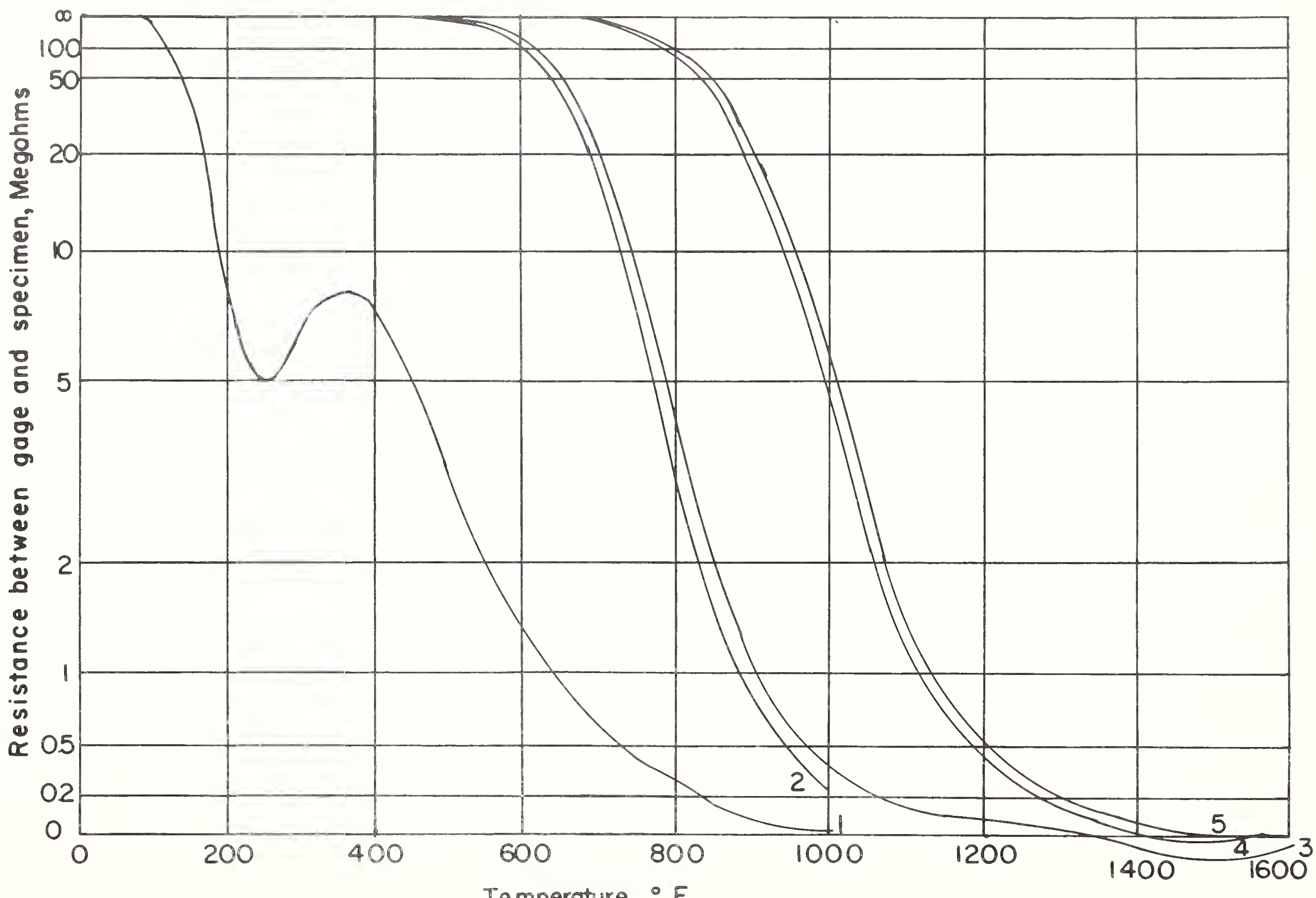


Fig. 24 Leakage resistance

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